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AN INVESTIGATION OF TERRESTRIAL REFRACTION

BY

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of
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AN INVESTIGATION OF TERRESTRIAL REFRACTION.

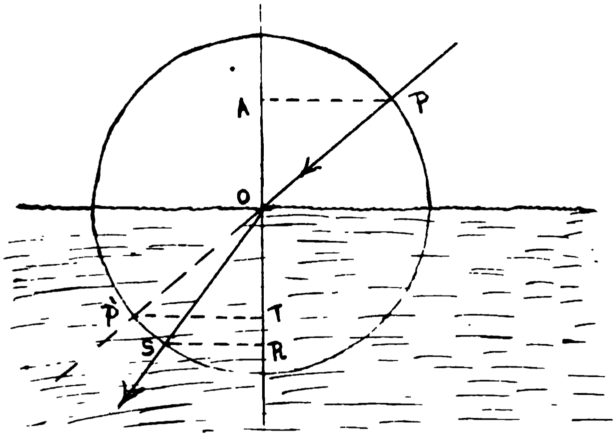
The history of the subject of refraction bears with it considerable of antiquity, although we have no knowledge of when it first began to be studied;but undoubtedly from the earliest times men were familiar with the effect that water has upon a body as seen in or through it.

The earliest record of atmospheric refraction having been considered is that of Clemonedes, who lived about the time of the Emperor Augustus. He suggested that the sun may be seen while it is still a little below the horizon. He also, like Archimedes, was acquainted with the fact that an object, in the bottom of a vessel, just invisible when viewed at an oblique angle, may be made visible by filling the vessel with water.

Ptolemy measured angles of incidence and refraction but failed to discover the true law of refraction; which was discovered by Snell in 1619. He stated it thus:- For the same media the ratio of the cosecants of the angle of incidence and angle of refraction retains always the same value. A few years later Descartes gave us the form we use to-day, that is, "the

law of sines." Huygens was the first to elaborate the subject of atmospheric refraction according to the undulatory theory of light.

When a ray of light passes from one transparent medium to another, it undergoes a change of direction at the surface of separation; so that its course in the second medium makes an angle with its course in the first. This changing of direction is what is known as refraction. The phenomenon can be exhibited by partly immersing a stick in water in an oblique position, when it will present a broken appearance. The amount of this displacement varies with different media.

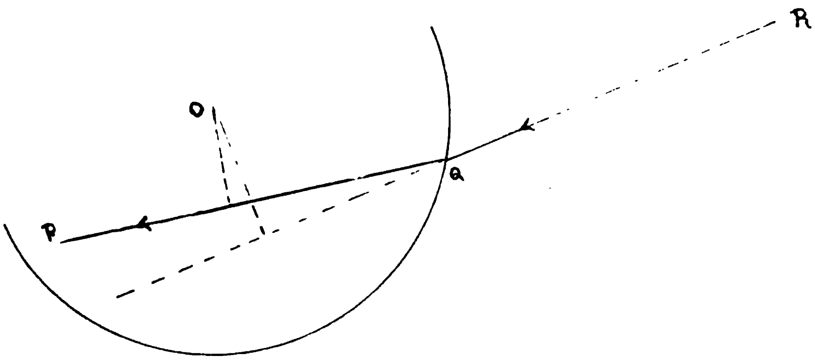


Snell's law can only be stated by reference to a geometrical figure or using the language of trigonometry. Let PO be a ray incident at O on the surface of separation of two media and let OS be its course after refraction. The angle POA, that is, the angle which the ray makes with the normal AR is called the angle of incidence and SOR is known as the

angle of refraction. With O, the point where the ray passes from one medium to the other, as a center describe a circle. Drop perpendiculars to the normal as PA or its equal P'T and SR. Then the law is that these perpendiculars will have a constant ratio. This ratio, with respect to a ray of light passing from a vacuum into any medium, is known as the index of refraction.

The index for Air is................1.0003.
Pure water is.........1.336.
Crown glass...........1.545.
Diamond...............2.596.

The atmosphere may be regarded as a medium which varies continuously according to some given law. Or it may be said to be in concentric spherical strata with the center of the earth for the center of the spheres. The refractive index at any point may be regarded as a function of the co-ordinates of that point. Equating this function to a constant, we obtain the equation of a surface along which the refractive index is constant.



Let PQ and QR be two consecutive directions of a ray, after being refraced at a spherical aurface whose center is O. If φ and φ' be the angles of incidence and refraction, and μ the index of refraction. Then $\mu \sin \varphi = \mu' \sin \varphi'$. If p and p' be the lengths of the perpendiculars drawn from O to the ray before and after refraction, this equation may be expressed in the form,

$$\mu p = \mu' p'.$$

Therefore if the ray be regarded as passing through a continually changing medium, stratified in spherical surfaces whose center is O, the equation of the ray may be expressed by the equation,

$$\mu p = a,$$

where a is a constant. If we take this spherical stratum as a layer of air with the center as the center of the earth, then p will be the perpendicular from the center of the earth on the tangent to the path at a point where the refractive index is μ.

Let x be the radius vector drawn from the center to any point of the path, this will be the normal to the stratum. Also let φ be the angle between the ray and this normal, then the preceding equation may be written in the form,

$$\mu x \sin \varphi = \mu_0 a \sin z,$$

where μ_0, a, and z are the values which they would assume at

at the center of the earth. If the consecutive elements of the path of the ray make an angle φ with the normal the deviation of $\varphi - \varphi'$ will be the increment of atmospheric refraction. If we denote this atmospheric refraction by r, then,

$$\varphi - \varphi' = \delta r$$

$$\mu \sin \varphi = (\mu + \delta \mu) \sin (\varphi - \delta r)$$

or,

$$\mu \sin \varphi = (\mu + \delta \mu) (\sin \varphi - \delta r \cos \varphi).$$

That is,

$$\delta \mu \sin \varphi - \mu \delta r \cos \varphi = 0$$

which gives

$$\frac{dr}{d\mu} = \frac{\tan \varphi}{\mu}.$$

If we substitute the value of φ in terms of z as obtained from the previous equation we find,

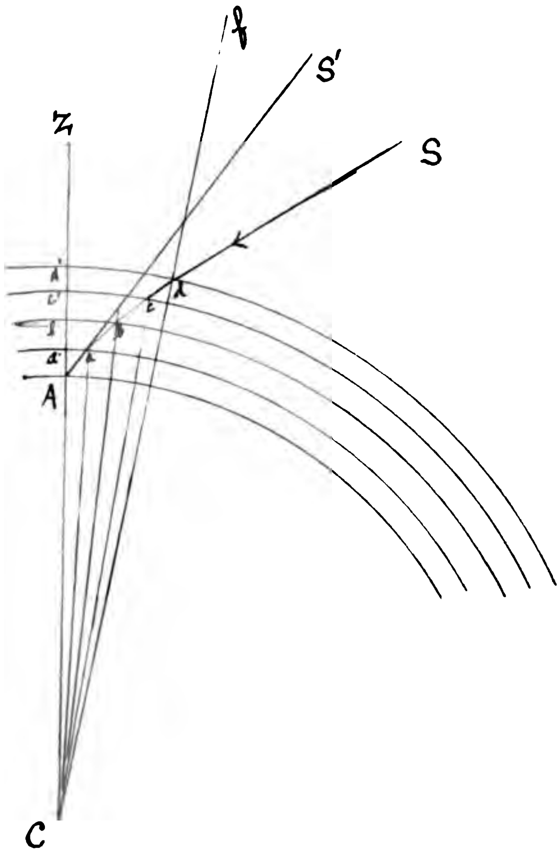
$$\frac{dr}{d\mu} = \frac{1}{\mu} \frac{\mu_0 a \sin z}{\sqrt{\mu^2 x^2 \mu_0^2 a^2 \sin^2 z}}$$

or,

$$r = \mu_0 a \int \frac{\sin z \, d\mu}{\mu \sqrt{\mu^2 x^2 \mu_0^2 a^2 \sin^2 z}}$$

as the general equation for refraction.

Let us again regard the atmosphere as composed of an infinite number of concentric spherical strata, whose common center is the center of the earth, each of which is of uniform density, and within which the path of a ray of light is a straight line.



Let dc, cb, ba, aA, be the successive refractions of a ray of light entering the atmosphere at d and reaching the earth at A. When the number of strata is regarded as infinite aA the last direction becomes a tangent to the curve then AaS' is the apparent direction of the star.

Let Cd, Cc, Cb, etc., be the normals to the successive strata. Sdf is the first angle of incidence. Cdc is the first angle of refraction.

At any point, say c, along the course of the ray, let,

i = the angle of incidence,

f = the angle of refraction,

μ = the index of refraction above point c, and

μ' = the index of refraction below point c.

Then,

$$\frac{\sin i}{\sin f} = \frac{\mu'}{\mu}. \qquad (1)$$

Let q = normal Cc to the upper of the two strata and q'= normal Cb to the lower of the two strata.

i' = angle of incidence to lower of the two strata.

Then, from triangle Ccb,

$$\frac{\sin i'}{\sin f} = \frac{q}{q'}$$

and

$$q\mu \sin i = q'\mu' \sin i',$$

which shows that the product of the normals to any stratum by its index of refraction and the sine of the angle of incidence is the same for any two strata, that is, it is constant for all strata.

If we put,

z = the apparent zenith distance,

a = the normal at the observer,

μ_0= the index of refraction of the air at the observer,

we have,

$$q\mu \sin i = a\mu_0 \sin z, \qquad (2)$$

in which the second member is constant for the same values of z and μ_0.

From (1) we have,

$$\tan \tfrac{1}{2}(i - f) = \frac{\mu' - \mu}{\mu' + \mu} \tan \tfrac{1}{2} (i + f).$$

But if $(i - f)$ is the refraction of the ray in passing from one stratum into the next and as we are supposing the densities of the strata to vary by infinitestimal increments $(i - f)$ is the differential of refraction.

Therefore we may write $\frac{1}{2}dr$ for $\tan \frac{1}{2} (i - f)$ and $d\mu$ for $\mu' - \mu$, also 2μ for $\mu' + \mu$ and $\tan i$ for $\tan \frac{1}{2} (i + f)$, hence,

$$dr = \frac{d\mu}{\mu} \tan i, \qquad (3)$$

which is the differential equation of refraction. Now suppose we assume that the law of decrease of density is such that some constant power of the refraction index μ is reciprocally proportional to the normal q.

This is expressed by the relation,

$$\left[\frac{\mu}{\mu_0}\right]^{n+1} = \frac{a}{q},$$

which from (2) gives

$$\sin i = \left[\frac{\mu}{\mu_0}\right]^n \sin z \qquad (4)$$

or, logarithmically,

$$\log \sin i = n \log \mu + \log \left[\frac{\sin z}{\mu_0^n}\right].$$

By differentiation,

$$\frac{di}{\tan i} = n \frac{d\mu}{\mu}$$

which from (3) gives $dr = \frac{di}{n}$

and integrating,

$$r = \frac{i}{n} + C.$$

To determine the constant C, the integral is to be taken from the upper limit of the atmosphere to the surface of the earth, at the upper limit $r = o$ and if we put $\theta =$ the value of i at that limit, we have,

$$o = \frac{\theta}{n} + C$$

at the lower limit the value of r is the whole atmospheric refraction, and $i = z$, hence,

$$r = \frac{z}{n} + C.$$

Eliminating the constant, we have,

$$r = \frac{z - \theta}{n}. \qquad (5)$$

In (4), by putting $\mu = 1$, since the density of the air at the upper limit is to be taken as zero, we find for θ

$$\sin \theta = \frac{\sin z}{\mu_0^n}. \qquad (6)$$

Find μ_0 at the surface of the earth and having determined this, we can combine (5) and (6) which gives,

$$r = \frac{1}{n} \left[z - \sin^{-1} \left(\frac{\sin z}{\mu_0^n} \right) \right]$$

which is known as Simpson's Formula.

For an approximate refraction the formula may be written

$$r = g \tan (z - fr)$$

which according to Bradley, for a mean state of the air corresponding to the barometer 29.6 and thermometer 50° Fahrenheit, expresses the observed refraction by taking,

$$g = 57.036'', \text{ and } f = 3.$$

In order to correspond with the real state of nature it is necessary that the constitution of the atmosphere which the hypothesis involves should not only agree with the observed refraction, but also with the height of the barometer and with the observed diminution of heat as the altitude of the observer above the earth's surface increases. Let us substitute the density of the air in the place of the index of refraction. Put,

δ_0 = density of air at the surface of the earth,

δ = density of air at any point above the surface.

Then,

$$\mu^2 - 1 = 4K\delta$$

expresses the relation between μ and δ, where $4K$ is a constant determined by experiment. According to Biot,

$$4K = 0.000588768.$$

Since the square of K will be inappreciable, we may take

$$\mu = (1 + 4K\delta)^{\frac{1}{2}} = 1 + 2K\delta$$

$$\mu_0 = 1 + 2K\delta_0$$

$$\mu_0^n = 1 + 2nK\delta_0 .$$

The relation,

$$\tan \frac{n}{2} r = \frac{\mu_0^{n-1}}{\mu_0^{n+1}} \tan (z - \frac{n}{2} r)$$

by neglecting K^2, becomes

$$\tan \frac{n}{2} r = nK\delta_0 \tan (z - \frac{n}{2} r).$$

If we denote the horizontal refraction, or that for $z = 90^0$, by r_0, the formula gives,

$$\tan \frac{n}{2} r_0 = nK\delta_0 \cot \frac{n}{2} r_0$$

or,

$$\tan \frac{n}{2} r_0 = \sqrt{nK\delta_0}$$

We can find δ_0 from the observed state of the barometer and thermometer at the surface of the earth, so that in order to compute the horizontal refraction by the formula, for the purpose of comparing it with the observed horizontal refraction, we have only to determine the value of n.

Let x = the height of any assumed point in the atmosphere above the surface of the earth,

$\delta p g$ = the density and pressure of the air and the force of gravity, respectively at that point,

$\delta_0 p_0 g_0$ = the same quantities on the earth's surface.

At an elevation greater than x by an infinitestimal dis-

tance dx, the pressure p is diminished by dp. The weight of a column of air whose height is dx, density δ and gravity g, is expressed by g δ dx, and this is equal to the decrement of the pressure; hence,

$$dp = -g\,\delta\,dx.$$

By the law of gravity, we have,

$$g = g_0\,\frac{a^2}{(a+x)^2},$$

hence,

$$dp = -g_0\,a^2\delta\,\frac{dx}{(a+x)^2}$$

$$= \quad g_0\,a\,\delta\,d\left[\frac{a}{a+x}\right].$$

Now, under the hypothesis, we have,

$$\frac{a}{a+x} = \left[\frac{\mu}{\mu_0}\right]^{n+1} = \left[\frac{1+4K\delta}{1+4K\delta_0}\right]^{\frac{n+1}{2}}.$$

Neglecting the square of K

$$\frac{a}{a+x} = 1 - 2\,(n+1)\,K\,(\delta_0 - \delta)$$

which gives

$$d\left[\frac{a}{a+x}\right] = 2\,(n+1)\,K\,d\delta,$$

hence,

$$dp = 2g_0\,a\,(n+1)\,K\delta\,d\delta.$$

Integrating,

$$p = g_0 a\,(n + 1)\,K\,\delta^2.$$

To compare this with the observed pressure p_0, let L = the height of a column of air of density δ_0 which acted upon by the gravity g_0 will be in equilibrium with the pressure p_0, then,

$$p_0 = g_0 \delta_0 L,$$

which with the last equation, gives

$$\frac{p}{p_0} = (n + 1)\frac{a}{L} \cdot \frac{K\delta^2}{\delta_0}.$$

At the surface of the earth, where p becomes p_0, and δ becomes δ_0, the equation gives

$$1 = (n + 1)\frac{a}{L} \cdot K\delta_0$$

whence

$$n = \frac{\frac{L}{a}}{K\delta_0} - 1.$$

This reduces the equation of the horizontal refraction to

$$r_0 = \frac{2\,K\delta_0}{\sqrt{\left[\frac{L}{a} - K\delta_0\right]}}$$

But according to Argelander it does not fully agree with observed refractions. This discussion is according to Chauvenet.

Refraction in solids or liquids, and even astronomical

refraction, that is, light from a star at not too great a zenith distance, has been accurately and quite satisfactorily determined, but if a large zenith distance is used or an object near the horizon as a distant terrestrial object, it has as yet not been disposed of in a satisfactory manner, owing to the varied and numerous apparently indeterminate agencies which seem to affect the passage of a ray of light through the lower strata of the atmosphere. Indeed the refraction at a zenith distance greater than 80° is known to vary 3' and 4' under, apparently, the same conditions.

The object of the following observations has been an examination of the principal agencies supposed to affect the passage of light near the horizon. They have been taken with a great deal of care in order to get them as accurate as possible and they have been combined in various ways in which it was thought possible to show any cause of variation of the zenith distance.

In addition to measuring the zenith distance of the object, the thermometer and barometer were always read; the direction and velocity of the wind noted; also the moisture of the atmosphere and the clearness or cloudiness of the weather.

The instrument used was that known as the Universal Instrument, Number 2598, Carl Bamberg, Berlin, being of the

broken telescope variety. The object glass is 35 millimeters clear aperture. There are two graduated circles, one horizontal of 17.5 centimeters diameter, and a vertical one of 16.4 centimeters diameter. Each circle is provided with two micrometer microscopes, thus making it possible to read to single seconds without difficulty.

Each day the instrument was mounted over the same point on the east steps of the Observatory and directed upon the water tank at the State Hostipal for the Insane, which is directly across Lake Mendota, at a distance of about four miles and less than eight minutes of arc above the horizon. The horizontal thread was set each time exactly over the line of division of the cylindrical and conical parts of the tank; as those are of different colors, the line of demarkation was perfectly distinguishable.

The order of observation was as follows:

One reading Circle Right.

Reverse Instrument and take a reading Circle Left.

Disturb level and take a second reading Circle Left.

Reverse Instrument and read again Circle Right.

Thus was furnished two double sets of readings, the means of which were taken. The level was carefully read each time immediately after setting the instrument and the level correction applied to the micrometer readings. The observations

were made each day at 12 o'clock, beginning the thirteenth of January and continuing every day the object could be seen, until the third of May, making a total of one hundred fifty-two readings.

As an example of the daily observations the following specimen is inserted.

DATE:- Tuesday, March 3, 1902.

HOUR:- 12.	WEATHER:- Cloudy.
THER.:- 29°.	MOISTURE:- 0.5.
BAR.:- 29.05 inches.	WIND:- N.E. Vel. 12.

CIR.	LEVEL		MIC. I.	II.	b	VERT. CIR.	ZENITH. Dist.
R.	6.8	27.4	89°50'20.0"	50' 28.0"	+1.9	89°50'49.9"	
L.	8.0	29.0	270 5 24.0	5 18.0	-4.7	270 5 37.3	89°52'36.3"
L.	5.5	25.4	270 5 17.5	5 12.0	+9.6	270 5 39.1	
R.	6.3	27.4	89 50 20.5	50 27.0	+3.1	89 50 50.6	89 52 35.8

The following is a tabular record of the observations arranged in chronological order. As in no case did the zenith distance vary outside the limits of 89° 52' and 89° 53' only the seconds are recorded in the tabulation. The meaning of each succeeding table will be understood from the heading.

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TABLE I.

OBSERVATIONS ON ASYLUM WATER TANK.

Date	Ther.	Bar.	Zenith Distance		Wind Direc.	Vel.	Weather	Moisture
Jan.	Degrees.	Inches.	89°	52'		Miles.		Degrees.
13	36°	29.13	30"	33"	S. W.	20	Clear	0.4
14	41	28.83	24	21	N. W.	8	Clear	0.6
15	34	29.05	31	31	N. W.	6	Fair	0.7
16	32	29.25	40	39	–	0	Clear	1.0
17	39	28.71	41	33	S.	20	Cloudy	0.9
18	37	29.05	22	20	N. W.	10	Clear	0.9
20	39	29.12	41	34	S.	15	Cloudy	1.0
21	36	29.08	24	31	N.	15	Cloudy	0.6
22	38	29.15	26	26	N. W.	2	Clear	0.5
24	34	29.18	31	29	N. W.	5	Clear	1.1
25	25	29.29	34	33	S.	12	Cloudy	0.5
28	10	29.89	18	23	S. W.	3	Clear	0.5
29	21	29.59	39	38	N. E.	10	Cloudy	1.1
30	29	29.39	25	24	S.	15	Fair	0.8
31	34	29.12	32	31	W.	10	Fair	1.2
Feb.								
1	24	29.09	44	39	N.	3	Fair	0.9
3	16	29.29	36	36	S. W.	5	Cloudy	0.2
6	22	28.89	44	43	S. W.	12	Clear	1.5
7	18	29.19	34	32	N. W.	18	Clear	1.3
8	18	29.29	30	33	N. W.	10	Clear	0.7
10	33	29.30	26	25	N. W.	8	Clear	1.7
11	25	29.07	33	33	N. W.	9	Cloudy	0.5
12	32	29.14	36	34	N. W.	8	Clear	2.1
13	33	29.46	42	44	N. E.	12	Clear	1.4
14	28	29.54	40	40	N.	14	Cloudy	1.4
15	33	29.24	37	40	S. W.	6	Clear	1.2
17	30	28.98	30	30	N. W.	15	Clear	0.5
18	33	29.03	30	32	N. W.	7	Clear	2.3
19	28	29.42	28	28	N. W.	3	Clear	2.1
20	34	29.34	44	43	S.	10	Clear	1.3
21	36	29.17	38	38	N.	4	Clear	2.8
24	53	29.14	37	36	N. W.	6	Clear	2.7
25	47	29.11	52	49	S.	15	Clear	2.5
26	50	28.72	40	41	S.	25	Fair	4.7
Mar.								
3	29	29.05	36	36	N. E.	12	Cloudy	0.5
4	31	29.29	40	40	N.	20	Cloudy	0.3
5	46	29.34	33	33	N.	4	Clear	2.7
6	50	29.04	50	50	S. W.	30	Clear	2.3

Date	Ther.	Bar.	Zenith Distance.		Wind Direc.	Vel.	Weather.	Moisture.
Mar.	Degrees.	Inches.				Miles.		Degrees.
13	53	29.19	36	36	S.	12	Clear	6.1
14	57	29.11	39	32	S.	30	Cloudy	4.7
17	16	29.37	24	24	N. W.	12	Fair	0.8
18	32	29.55	51	52	S. W.	10	Clear	2.4
19	42	29.21	40	41	S.	24	Fair	1.8
20	42	29.24	35	30	S.	15	Cloudy	1.6
21	42	29.29	41	38	N. E.	4	Cloudy	3.5
22	47	29.29	41	37	N.	7	Fair	3.5
24	59	29.21	23	27	S. E.	10	Fair	4.6
25	59	29.91	28	28	S. E.	12	Clear	3.4
27	69	28.93	50	49	S. W.	20	Clear	3.9
28	50	28.70	37	34	N. E.	12	Cloudy	0.5
29	60	28.87	29	28	N. W.	8	Cloudy	0.5
31	45	29.00	44	44	N. W.	15	Cloudy	0
Apr.								
1	40	29.08	38	39	N. W.	10	Cloudy	0.8
2	45	29.10	39	42	N. W.	9	Cloudy	0.6
3	56	29.36	42	40	N. W.	4	Clear	2.3
4	51	29.19	40	40	N. E.	7	Clear	3.5
7	32	29.25	40	40	N. W.	15	Cloudy	1.8
8	42	29.28	42	42	N. W.	5	Cloudy	1.5
9	65	29.19	32	32	N. W.	5	Clear	3.8
10	71	29.07	47	40	S. W.	18	Clear	0.9
11	61	28.90	40	38	W.	42	Fair	10.8
12	52	29.09	32	35	N.	11	Cloudy	3.7
14	51	29.37	42	38	N.	8	Fair	7.5
15	53	29.32	41	46	N.	7	Fair	7.4
16	55	29.10	38	39	S.	3	Fair	5.8
17	68	28.97	32	27	N. W.	12	Fair	10.7
19	54	29.13	40	39	N.	7	Fair	4.8
21	80	28.64	41	42	S.	32	Fair	13.9
23	57	29.17	33	33	W.	12	Fair	6.5
24	57	29.34	39	37	S.	10	Clear	9.1
28	67	29.04	37	35	S.	15	Cloudy	8.3
29	76	28.95	37	31	N. W.	20	Clear	11.0
30	62	29.29	39	39	N.	6	Clear	7.5
May								
1	63	29.21	26	23	S.	20	Fair	10.4
2	82	28.89	41	35	W.	15	Clear	19.0
3	65	28.99	39	40	S.	16	Cloudy	3.7

TABLE II.

VARIATIONS OF 5° IN TEMPERATURE.

	16° to 20°	21° to 25°	26° to 30°	31° to 35°	36° to 40°	41° to 45°	46° to 50°	51° to 55°	56° to 60°	61° to 65°
	36"	39'	40'	40"	30"	40"	33"	40"	42"	40"
	36	38	40	40	33	41	33	40	40	38
	24	44	28	39	24	19	41	42	28	39
	24	43	25	40	31	23	37	38	28	39
	34	34	24	36	38	44	40	32	33	26
	32	32	36	34	38	38	33	35	33	23
	30	44	36	39	22	42	50	36	39	32
	33	39	30	40	20	42	50	31	37	31
		33	29	26	26	44		37	23	39
		33	28	25	26	44	40	36	27	40
				42	41	39	41	41	29	
				44	31	42	37	46	28	
				37	41		34	39		
				40	35			32		
				30	38			40		
				32	39			39		
				28				30		
				31				39		
				31						
				29						
				33						
				31						
				44						
				43						
Means	31"	38"	32"	36"	32"	39"	39"	38"	32"	35"

EXTREME TEMPERATURES.

	10°	66° - 70°	71°	76°	80°	82°
	18"	37"	47"	37"	41"	41"
	23	35	40	31	42	35
		32				
		27				
		50				
		49				
Means	21"	40"	44"	34"	42"	38"

TABLE III.

OBSERVATIONS ACCORDING TO DIRECTION OF WIND.

	SOUTH.	SOUTH W.	WEST.	NORTH W.	NORTH.	NORTH E.	SOUTH E.
	41"	30"	32"	24"	24"	39"	23"
	33	33	31	21	31	38	27
	41	18	40	31	44	32	28
	34	23	38	31	39	44	28
	34	36	33	22	40	36	
	33	44	33	20	40	36	
		43	41	26	38	41	
	44	37	35	26	38	38	
	43	40		31	40	37	
	52	50		29	40	34	
	49	50		34	33	40	
	40	51		32	33	40	
	41	52		30	41		
	36	50		33	37		
	35	43		26	42		
	39	47		25	38		
	32	40		33	41		
	40			33	46		
	41			36	40		
	35			34	39		
	30			30	39		
	38			29	39		
	39			30			
	41				NORTH W.		
	42			32	40		
	39			28	42		
	37			28	42		
	37			37	32		
	35			38	31		
	26			24	32		
	23			24	35		
	39			29	32		
	40			28	27		
	25			44	37		
	24			44	31		
				38			
				39			
				39			
				42			
				42			
				40			
				39			
Means	37"	40"	35"	33"	38"	39"	27"

TABLE IV.

OBSERVATIONS ACCORDING TO VELOCITY OF WIND.

Miles-0-3	4-6	7-9	10-12	13-15	16-18	19-21	24-25	30-32	42
40"	38"	30"	22"	40"	39"	30"	40"	50"	41"
39	38	32	20	40	40	33	41	50	38
26	33	41	39	41	34	41	40	39	
26	33	37	38	34	32	33	41	32	
44	41	40	32	24	47	40		41	
39	38	40	31	31	40	40		42	
18	42	41	30	25		37			
23	40	46	33	24		31			
28	31	40	44	30		26			
28	29	39	43	29		23			
39	36	21	52	49					
	42	26	23	35					
	42	25	27	30					
	32	33	40	44					
	31	33	39	44					
	31	36	32	37					
	37	34	35	35					
	40	29	34	41					
	37	28	33	35					
	36	42	44	39					
		38							
	39	39	43	40					
	39	42	42						
			44						
			36						
			36						
			36						
			35						
			24						
			24						
			28						
			28						
			37						
			34						
			32						
			27						
			33						
			33						
Means 32"	36"	35"	35"	36"	38"	34"	40"	42"	39"

TABLE V.

RECORDS BEFORE ICE WENT OUT.

Low Ther.		High Ther.	
10°	18" - 23"	36°	30" - 33"
16	36 - 36	36	24 - 31
16	24 - 24	36	38 - 38
18	34 - 32	37	22 - 20
18	30 - 33	38	20 - 22
21	39 - 38	39	41 - 31
22	44 - 43	39	41 - 35
23	34 - 32	41	40 - 41
24	44 - 39	42	19 - 23
28	40 - 40	42	35 - 30
28	28 - 28	42	41 - 38
29	25 - 24	46	33 - 33
29	36 - 36	47	41 - 37
30	30 - 29	48	40 - 33
31	40 - 40	50	50 - 50
32	39 - 40	50	40 - 40
32	36 - 34	50	37 - 34
33	26 - 25	53	36 - 31
33	37 - 40	53	37 - 36
33	42 - 44	54	39 - 32
33	30 - 32	57	28 - 28
34	28 - 31	59	23 - 27
34	31 - 29	60	29 - 28
34	33 - 31	69	50 - 49
34	44 - 43		
Means	34"		34"

TABLE VI.

RECORDS AFTER ICE WENT OUT.

Low Ther.		High Ther.	
32°	39" - 40"	61°	40" - 38"
40	38 - 39	62	34 - 39
42	42 - 42	63	26 - 23
45	39 - 42	65	32 - 31
45	44 - 44	65	39 - 40
51	40 - 40	67	37 - 35
51	42 - 38	68	32 - 27
52	32 - 35	71	47 - 40
53	41 - 46	76	37 - 31
54	38 - 39	80	41 - 42
55	40 - 39	82	41 - 35
56	42 - 40		
57	33 - 33		
57	39 - 37		
Means	39"		36"

TABLE VII.

	Cloudy Days.		Clear Days.			Fair Days.	
	41"	35"	30"	36"	36"	31"	27"
	33	30	33	34	35	31	39
	41	41	24	42	51	25	39
	34	38	21	44	52	24	41
	24	37	30	37	28	40	42
	31	34	40	40	28	41	33
	34	29	22	30	50	24	33
	33	28	20	29	49	24	26
	39	44	26	30	49	40	23
	38	44	26	32	42	41	
	44	38	31	28	40	41	
	39	39	29	28	40	37	
	36	39	18	44	40	23	
	36	41	23	43	32	27	
	33	39	32	38	31	40	
	33	40	31	38	47	38	
	40	42	44	36	40	42	
	40	42	43	52	39	38	
	36	32	34	49	37	41	
	36	35	32	33	37	46	
	40	37	30	33	31	38	
	40	35	33	50	39	39	
	40	39	26	50	39	32	
	32	40	25	41			
				35			
Means		37"			35"		35"

TABLE VIII.

Cloudy Days and Low Ther.	Cloudy Days and High Ther.	Clear Days and Low Ther.	Clear Days and High Ther.
36"	38"	18"	24"
36	39	18	21
44	35	23	33
39	30	34	33
33	41	32	32
33	38	30	49
34	44	33	50
33	44	44	50
40	39	43	36
40	42	30	35
39	42	29	37
39	42	36	36
36	37	34	42
36	34	39	40
40	32	40	28
40	35	30	28
39	39	32	39
40	32	44	37
24	39	43	39
31	40	40	39
41	37	29	32
33	35	32	31
41	28	31	47
34	29	30	40
		33	37
		38	31
		38	41
		22	35
		20	
		26	
		26	
Means 37"	37"	33"	37"

TABLE IX.

Cloudy Days and High Wind	Clear Days and High Wind	Cloudy Days and Low Wind	Clear Days and Low Wind
41"	30"	36"	24"
41	33	36	21
34	34	33	22
24	32	33	20
31	30	41	31
41	29	40	29
40	52	36	44
40	49	36	43
40	50	36	30
39	50	34	31
32	49	29	26
35	47	28	25
30	40	38	36
44	37	39	34
44	31	39	42
39	41	42	44
40	35	42	37
37		32	40
35		35	30
39			32
40			44
			43
			36
			35
			51
			52
			28
			28
			40
			32
			31
			39
			37
			39
			39
Means 38"	39"	36"	35"

TABLE X.

ACCORDING TO MOISTURE IN ATMOSPHERE.

	1.9 to 9.1	8.3 to 5.7	4.8 to 3.5	2.8 to 2.0	1.8 to 1.0	0.9 to 0.0	
	41"	37"	40"	51"	40"	47"	24"
	39	35	39	52	41	40	31
	41	42	23	50	35	40	22
	42	38	27	50	30	39	20
	37	41	40	32	44	39	41
	31	46	41	33	43	41	33
	32	39	39	52	37	38	31
	27	39	32	49	40	38	31
	26	33	39	37	40	44	24
	23	33	40	36	40	44	21
	40	38	32	38	42	29	30
	38	39	31	38	44	29	
	39	32	40	26	26	37	
	37	35	40	26	29	34	
		36	50	30	34	24	
		35	49	32	42	24	
			28	36	44	40	
			28	34	43	40	
			41		32	36	
			41		31	36	
			38		39	30	
			37		38	29	
					31	33	
					29	33	
					40	33	
					39	36	
						44	
						39	
						25	
						24	
						18	
						23	
						34	
						33	
						26	
						26	
Means	35"	37"	37"	39"	37"		33"

TABLE XI.

ACCORDING TO BAROMETRIC READINGS.

Inches	28.64 to 29.00	28.91 to 29.10	29.11 - 29.36		29.31 to 29.50	29.51 to 29.91
	41"	30"	30"	32"	29"	39"
	42	29	33	40	24	38
	41	32	40	41	26	18
	35	27	39	35	25	23
	40	37	41	30	42	28
	38	31	34	41	44	28
	29	39	26	38	28	40
	28	37	26	41	28	40
	37	31	31	37	44	
	34	31	29	23	43	
	44	22	34	27	33	
	43	20	33	40	33	
	41	24	32	40	24	
	33	31	31	39	24	
	24	44	36	40	42	
	21	39	36	32	40	
	40	33	34	31	42	
	41	33	32	40	38	
		30	30	34	41	
		32	33	33	46	
		36	26	26	39	
		30	25	23	37	
		50	36			
		50	34			
		49	37			
		44	40			
		39	38			
		42	38			
		42	39			
		32	39			
		35	37			
		47	38			
		40	32			
		38	42			
		39	44			
		37	36			
		35	35			
Means	38"	35"		35"	35"	32"

TABLE XII.

SUMMARY.

VARIATIONS OF 5° IN TEMPERATURE.

Degrees	16° - 20°	21° - 25°	26° - 30°	31° - 35°	36° - 40°
Means	31"	38"	32"	36"	32"
	41° - 45°	46° - 50°	51° - 55°	56° - 60°	61° - 65°
	39"	39"	38"	32"	35"

EXTREME TEMPERATURES.

Degrees	10°	66° - 70°	71°	76°	80°	82°
Means	21"	40"	44"	34"	42"	38"

ACCORDING TO DIRECTION OF WIND.

Dir...	SOUTH.	SOUTH W.	WEST.	NORTH W.	NORTH.	NORTH E.	SOUTH E.
Means	37"	40"	35"	33"	38"	39"	27"

ACCORDING TO VELOCITY OF WIND

Miles	0-3	4-6	7-9	10-12	13-15	16-18	19-21	24-25
Means	32"	36"	35"	35"	36"	38"	34"	40"
	30-32	42						
	42"	39"						

BEFORE ICE WENT OUT.

Low ther. (10° - 34°)	34"
High ther. (36° - 69°)	34"

AFTER ICE WENT OUT.

Low ther. (32° - 57°)	39"
High ther. (61° - 82°)	36"

Cloudy Days	37"
Clear Days	35"
Fair Days	35"

CLOUDY DAYS.

Low ther. (16° - 39°)	36"
High ther. (40° - 82°)	37"

CLEAR DAYS.

Low ther. (10° - 37°)	34"
High ther. (38° - 80°)	37"

Cloudy Days and High Wind	38"
Clear Days and High Wind	39"
Cloudy Days and Low Wind	36"
Clear Days and Low Wind	35"

ACCORDING TO MOISTURE IN ATMOSPHERE.

	19 to 9.1	8.3 to 5.7	4.8 to 3.5	2.8 2.0	1.8 to 1.0	0.9 to 0.0
Means	35"	37"	37"	39"	37"	33"

ACCORDING TO BAROMETRIC READINGS.

In. 28.64 to 29.00	28.91 to 29.10	29.11 to 29.30	29.31 to 29.50	29.51 to 29.91
38"	35"	35"	35"	32"

LOWEST FOUR READINGS OF BAROMETER.

Inches	28.64	41" - 42"
	28.70	37 - 34
	28.71	41 - 33
	28.72	40 - 41

HIGHEST FOUR READINGS OF BAROMETER.

Inches	29.91	28" - 28"
	29.89	18 - 23
	29.59	39 - 38
	29.55	51 - 52

It may be noted that the smallest zenith distance found, occurs with the lowest reading of the thermometer and the second highest reading of the Barometer. i.e, January 25, Thermometer 10°, Barometer 29.89, Zenith 89° 52' 18", Velocity of wind 3 miles, Moisture 0.5. Also the lowest reading of the Barometer occurs with the second highest thermometer, High wind and second greatest moisture, i.e., Barometer 28.64, Thermometer 80°, Moisture 13.9., Velocity of wind 32 miles. But the zenith distance, 89° 52' 41", is near the average reading.

MEAN OF ALL OBSERVATIONS.

89° 52' 35.7"

SMALLEST SINGLE READING.

89° 52' 18"

LARGEST SINGLE READING.

89° 52' 52"

TOTAL VARIATION.

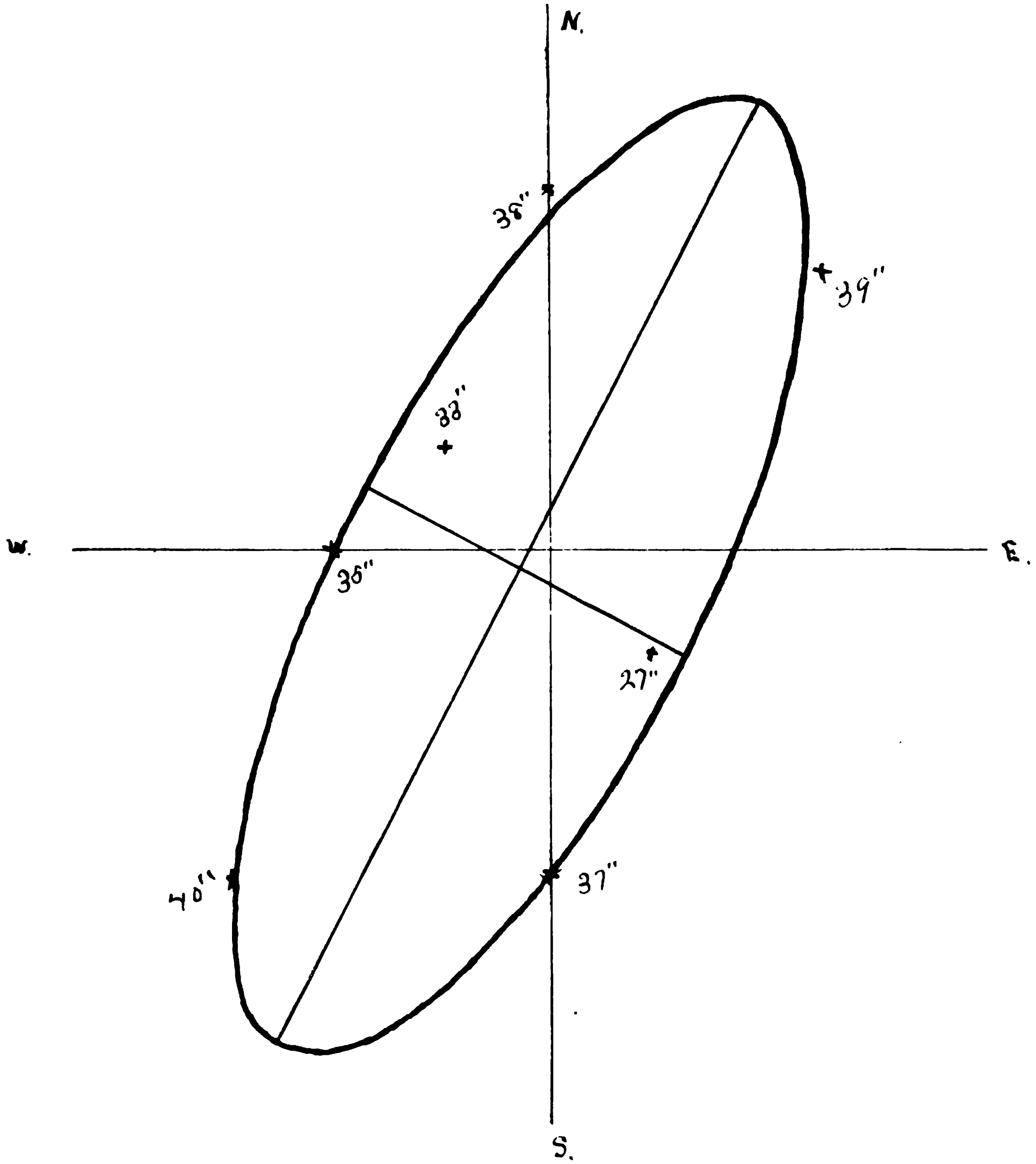
34"

Lowest Velocity of Wind, (0-3) miles	32"
Highest Velocity of Wind,(42) miles	39
Wind S.W.	40
Wind N.W.	39
Wind N.E.	39
Wind S.E.	27
" S	37
" N	38
Lowest Thermometer (10°)	18"
Highest Thermometer (80°)	42
Lowest Barometer (28.64 - 29.00)	38
Highest Barometer (29.51 - 29.91)	32

In general, from the records, it seems that the greatest zenith distance occurs when there is a high thermometer, a high wind, a low barometer, and when the air contains a large amount of moisture and on cloudy rather than on clear days.

It may be worthy of mentioning also that the mean readings, with respect to the direction of the wind, when plotted are seen to lie nearly on an ellipse, the major axis of which is

at right angles to the general direction of the lakes. The following figure illustrates the fact.



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SUPPLEMENT.

The following series of observations are offered as a supplement to the thesis proper. The readings and methods of work have been carried out precisely as in the former series. The same number of observations was taken as before, but instead of taking one a day at twelve o'clock, two were taken at nine o'clock and four o'clock, respectively. The latter series are believed to be rather more accurate inasmuch as they were taken in mid-summer (between June 20th and August 10th) under much more favourable conditions of the weather. However, the mean readings and the range of variations are not decidedly different.

The smallest single reading 89° 52' 22" occurred on June 27th, Thermometer 79°, Barometer 29.11, Wind, South, Velocity, 1 mile, Moisture, 0.52, Weather, clear.

The largest single reading 89° 52' 56" occurred on July 14th. Thermometer, 88°, Barometer, 29.14, Wind, Northwest, Velocity, 3 miles, Moisture, 0.48, Weather, clear

The mean of all readings, 89° 52' 37".4.

OBSERVATIONS FOR REFRACTION.

Date.	Hour.	Thermom. Degrees.	Barom. Inches.	Zenith Distance. 89° 52'		Wind. Direc.	Veloc. Miles.	Moisture. Inches.	Weather.
June									
20	9:45	63	28.91	45.9	44.1	N.	13	.37	Cloudy
22	9:00	65	28.90	37.8	37.7	N. E	5	.40	Cloudy
22	4:00	67	28.87	35.3	35.5	N. E.	4	.40	Fair.
23	3:30	70	28.90	36.4	37.3	N. W.	10	.27	Fair.
23	9:15	70	28.89	31.7	32.9	N. W.	7	.27	Fair.
24	9:00	77	28.94	45.2	47.8	N. W.	6	.42	Fair.
24	4:30	79	28.89	38.6	39.7	N. W.	6	.42	Cloudy.
25	9:00	74	29.11	48.0	44.5	S. W.	2	.41	Clear.
25	4:00	79	29.10	38.3	42.2	N.	4	.60	Clear.
26	9:10	78	29.18	48.6	48.8	N.	4	.50	Clear.
26	4.40	79	29.11	36.5	35.0	N. E.	5	.51	Clear.
27	9:00	79	29.11	22.4	32.6	S.	1	.52	Clear.
27	4:00	81	29.01	35.0	35.9	N.	5	.69	Clear.
29	9:15	85	28.90	40.1	42.0	S. W.	3	.64	Cloudy.
29	4:00	86	28.90	38.8	34.1	S.	3	.76	Cloudy
30	9:30	77	28.86	31.8	37.0	S. W.	14	.66	Cloudy.
30	4:20	76	28.86	32.5	31.4	S.	12	.79	Fair.
July									
1	9:00	89	28.79	44.6	40.8	S.	14	.79	Fair.
1	4:00	86	28.86	34.2	34.4	W.	10	.81	Clear.
2	9:00	78	28.98	30.6	32.8	E.	2	.79	Cloudy.
2	4:00	87	28.94	35.4	34.2	S. W.	8	1.97	Fair.
3	9:00	86	29.20	43.0	44.8	S.	14	.78	Fair.
3	4:00	86	29.00	39.9	33.9	S.	12	.91	Fair.
4	9:00	81	28.94	36.9	35.7	S.	12	.76	Cloudy.
6	9:00	85	29.42	40.8	41.8	W.	5	.60	Clear.
6	4:00	85	29.24	33.5	35.7	S	14	.82	Clear.
7	9:00	85	29.23	43.6	42.9	S.	13	.63	Clear.
7	4:00	89	29.16	35.2	34.7	S	14	.91	Clear.
8	9:00	91	29.15	38.5	39.3	S	6	.73	Fair.
8	4:30	85	29.13	30.5	30.4	S.	5	.94	Fair.
9	9:00	82	29.10	33.8	34.5	S.	11	.68	Fair.
9	3:40	77	29.40	29.9	36.7	N. E.	16	.73	Cloudy.
10	9:00	89	29.09	35.6	33.9	S. W.	4	.69	Clear.
10	4:00	82	29.09	29.7	31.4	N. E.	4	.78	Cloudy.
11	9:00	89	29.07	38.9	37.4	N. W.	4	.64	Clear.
11	4:00	84	29.00	29.9	33.8	W.	7	.72	Clear.
13	9:00	83	29.03	36.5	36.2	N. W.	5	.46	Clear.
13	4:00	67	29.08	34.8	32.7	N. W.	10	.59	Fair.

OBSERVATIONS FOR REFRACTION.

Date.	Hour.	Thermom. Degrees.	Barom. Inches.	Zenith Distance. 89° 52'		Wind. Direc.	Veloc. Miles.	Moisture. Inches.	Weather
July									
14	9:20	88	29.14	55.5	46.7	N. W.	3	.48	Clear.
14	4:30	77	29.12	36.4	36.3	N.	8	.58	Fair..
15	9:00	73	29.24	37.4	40.1	E.	5	.33	Clear.
16	4:15	82	29.11	35.8	31.2	S.	4	.48	Clear.
17	9:00	69	28.94	34.7	24.4	S.	11	.53	Cloudy.
20	9:00	85	29.08	39.9	44.6	N. W.	5	.50	Clear.
20	4:00	82	29.08	31.5	37.6	N. W.	5	.63	Fair.
21	9:15	83	28.92	37.3	39.1	S. W.	13	.58	Fair.
21	4:15	90	28.97	33.2	30.2	N. W.	12	.66	Fair.
22	9:00	77	29.14	41.0	43.9	N.	4	.53	Fair.
22	4:15	79	29.20	39.3	35.2	N. W.	6	.66	Fair.
23	9:00	82	29.32	51.9	44.4	E.	1.	.58	Clear.
23	4:00	83	29.31	40.1	39.9	N.	3	.72	Clear.
24	9:00	85	29.32	42.3	39.7	S.	5	.59	Clear.
24	4:00	86	29.25	33.2	36.6	S.	12	.83	Clear.
25	9:00	89	29.22	43.3	47.6	S. W.	8	.63	Clear.
25	4:00	88	29.18	33.9	34.5	S. W.	15	.89	Clear.
27	9:00	70	29.24	40.6	33,1	E.	2	.51	Cloudy.
28	9:00	88	28.97	43.7	44.2	S.	8	.74	Clear.
28	4:00	89	29.88	35.8	40.4	S. W	12	.92	Cloudy .
29	9:00	90	28.96	34.3	33.7	S. W.	5	.65	Cloudy.
29	4:15	81	28.85	36.5	32.7	S.	6	.73	Clear
30	9:00	70	29.10	39.1	38.3	N. W.	9	.44	Fair.
31	9:00	74	29.32	36.5	33.6	N. E.	3	.42	Clear.
August									
1	9:00	69	29.32	35.6	42.6	S. E.	10	.48	Cloudy.
1	4:00	72	29.23	37.6	38.3	S. E.	19	.60	Cloudy.
4	9:00	70	29.10	31.2	34.4	N. E.	3	.61	Cloudy.
4	4:00	70	29.04	38.4	35.5	E.	6	.75	Clear.
5	9:20	70	28.91	40.5	40,6	S.	16	.76	Cloudy.
5	4:00	83	28.92	37.0	33.4	S. W.	6	.77	Clear.
6	9:00	76	29.06	40.0	40.2	N. W.	10	.52	Fair.
7	9:00	76	29.23	38.9	42.3	S.	3	.39	Clear.
7	4:00	73	29.14	39.3	31.3	S. W.	9	.55	Fair.
8	9:30	91	28.97	37.5	37.3	S. W.	6	.52	Cloudy.
8	4:00	78	28.88	36.0	32.8	S. W.	9	.64	Fair.
10	9:00	74	28.98	35.1	34.0	S.	9	.45	Cloudy.
10	4:00	71	28.99	35.8	28.4	W..	8.	.54	Clear.

Mean Zenith Distance, 89° 52' 37.4".

OBSERVATIONS ACCORDING TO BAROMETER.

Inches.	28.79 to 28.89	28.90 to 28.99	29.00 to 29.09	29.10 to 29.19	29.20 to 29.29	29.30 to 29.42
	46"	38"	40"	38"	43"	40"
	41	38	34	42	45	40
	22	36	30	34	39	52
	31	34	34	34	35	44
	32	34	35	39	43	42
	31	34	36	38	48	40
	34	40	41	31	43	36
	34	42	44	34	43	34
	34	46	38	48	38	36
	34	44	36	44	38	42
	36	41	40	36	39	30
	33	41	40	35	42	36
	35	37	39	22	34	41
	35	39	37	32	36	42
	36	37	35	36	37	
	40	34	33	31	40	
	36	45	40	36	40	
	33	48	44	36	33	
	32	35	32	30	33	
	33	44	37	30	36	
	39	37	35	36		
	40	36	34	36		
		35	30	55		
		24	31	47		
		33		39		
		30		31		
		44		38		
		44		39		
		37		35		
		37		35		
		31		49		
		33		49		
		35		34		
		34		34		
		36				
		28				
Mean,	34.9	37.2	36.5	36.3	39.2	39.6

OBSERVATIONS ACCORDING TO BAROMETRIC READINGS ON

Cloudy Days.			Fair Days.		Clear Days.			
28.80 to 28.90	28.90 to 29.00	29.00 to	28.80 to 28.90	28.90 to 29.00	28.80 to 29.00	29.00 to 29.10	29.10 to 29.20	29.20 to 29.40
	Inches.		Inches.			Inches.		
39	46	30	35	36	34	35	48	41
40	44	37	36	37	34	36	45	42
36	38	30	32	35	36	35	38	34
40	38	31	33	34	33	34	42	36
32	40	41	32	37	45	39	49	37
31	42	33	31	39	48	37	49	40
	39	36	45	33	37	30	35	52
	34	41	41	30	33	34	35	44
	31	38	36		35	36	22	42
	33	38	36		28	40	39	40
	37	31				45	35	33
	36	34				38	35	37
	35					36	55	44
	24						48	48
	34						36	36
	34						31	34
	41						34	39
	41						34	42
	37							
	33							
	37							
	37							
	34							
	35							
Means—36.33	36.25	35.00	35.4	35.1	36.3	36.5	39.4	39.5

VARIATIONS ACCORDING TO TEMPERATURE.

	63°–67°.	68°–72°.	73°–77°.	78°–82°.	83°–87°.	88°–92°.
	46	35	48	49	36	55
	44	24	46	49	36	47
	38	36	37	31	37	34
	38	36	40	33	39	34
	35	32	36	36	40	44
	35	33	34	33	40	44
	35	41	39	39	37	45
	33	33	31	40	33	41
		39	35	38	30	35
		38	34	42	34	35
		38	32	36	42	35
		38	31	35	41	34
		38	39	22	42	39
		31	42	32	44	37
		37	45	39	43	43
		34	48	35	30	47
		38	32	35	30	36
		36	31	36	40	40
		41	33	37	44	33
		41	37	33	42	30
		36	36	37	40	34
		36	36	33	39	34
		42	41	34	34	39
		28	44	34	34	39
			40	28	34	37
			40	31	43	37
				36	44	
				31	40	
				32	34	
				37	33	
				52	36	
				44	35	
					34	
Mean,	38	35.3	38	36	37	38

OBSERVATIONS ACCORDING TO WEATHER AND TEMPERATURE.

Cloudy Days.								Clear Days.			
High Thermometer.				Low Thermometer.				High Thermometer.			
Tem.	Bar.	Z.	D.	Tem.	Bar.	Z.	D.	Tem.	Bar.	Z.	D.
77°	29.40	30	37	63°	28.91	46	44	84°	29.00	30	34
78	28.98	31	33	65	28.90	38	38	85	29.42	41	42
79	28.89	39	40	69	28.94	35	24	85	29.24	34	36
81	28.94	37	36	69	29.32	36	42	85	29.23	44	43
82	29.09	30	31	70	29.24	41	33	85	29.08	40	44
85	28.90	40	42	70	29.10	34	41	85	29.32	42	40
86	28.90	34	34	70	28.91	41	41	86	28.86	34	34
89	28.88	36	40	71	28.97	37	37	86	29.25	33	36
90	28.86	34	34	72	28.86	32	31	88	29.14	55	47
				72	29.23	38	38	88	29.18	34	34
				74	28.98	35	34	88	28.97	44	44
								89	29.09	35	34
								89	29.16	35	35
								89	29.07	39	37
								89	29.22	43	47
Means -	28.97	35.4			29.03	36.6			29.05	37	

OBSERVATIONS ACCORDING TO WEATHER AND TEMPERATURE.

Fair Days.								Clear Days.			
High Thermometer.				Low Thermometer.				Low Thermometer.			
Tem.	Bar.	Z.	D.	Tem.	Bar.	Z.	D.	Tem.	Bar.	Z.	D.
77°	29.12	46	44	67°	29.08	35	33	83°	28.92	37	33
77	29.04	41	44	67	28.87	35	35	83	29.31	40	40
79	29.20	39	35	70	28.90	36	37	83	29.03	36	36
82	29.10	34	34	70	28.89	32	33	82	29.32	52	44
82	29.08	32	37	70	29.10	39	38	82	29.11	36	31
83	28.92	37	39	73	29.14	39	31	81	28.86	36	33
85	29.13	30	33	76	28.86	32	31	81	29.01	35	36
86	29.20	43	45	76	29.06	40	40	79	29.11	22	32
86	29.00	40	34	78	26.88	36	33	79	29.11	36	35
87	28.94	35	34					79	29.10	38	42
89	28.79	44	41					78	29.18	49	49
90	28.97	33	30					77	28.94	45	48
91	29.15	39	39					76	29.23	39	42
								74	29.32	36	34
								74	29.11	48	45
								73	29.24	37	40
								71	28.99	36	28
								70	29.04	38	36
Mean -	29.05	37.1			28.96	35.3			29.11	38.3	

OBSERVATIONS ACCORDING TO WEATHER AND TEMPERATURE.

Clear Days. Thermometer		Fair Days. Thermometer.		Cloudy Days. Thermometer	
Low	High.	Low	High.	High	Low
70°–83°	84°–91°	67°–78°	77°–91°	77°–90°	63°–74°
38	30	35	36	30	46
36	34	33	36	39	44
36	41	35	41	31	38
28	42	35	44	33	38
37	34	36	39	39	35
40	36	37	35	40	24
48	44	32	34	37	36
45	43	33	34	36	42
35	40	39	32	30	40
34	45	38	37	31	33
39	42	39	37	40	31
42	40	31	39	42	34
45	34	32	30	34	41
48	34	31	30	34	41
49	33	40	43	36	37
49	37	40	45	40	37
38	55	36	40	34	32
42	47	33	34	34	31
36	34		35		37
35	34		34		38
22	44		44		35
32	44		41		34
35	35		33		
36	34		30		
36	35		39		
33	35		39		
36	39				
31	37				
52	43				
44	47				
36					
36					
40					
40					
37					
33					
38.8	39	35.3	37	39.8	36.5

OBSERVATIONS ACCORDING TO WEATHER.

Cloudy Days.	Clear Days.		Fair Days.	
44	45	52	35	39
46	48	44	35	31
38	48	40	36	36
38	45	40	37	33
39	38	42	32	
40	42	40	33	
40	49	33	32	
42	49	36	31	
39	36	43	44	
42	35	47	41	
32	22	34	35	
31	32	34	34	
31	35	44	43	
33	36	44	45	
37	34	36	40	
36	34	33	34	
30	41	36	39	
37	42	34	39	
30	44	38	30	
31	43	36	30	
34	35	37	34	
24	35	33	34	
41	36	39	35	
33	34	42	33	
36	39	36	32	
40	37	28	37	
36	30		37	
42	34		39	
38	36		33	
38	36		30	
31	55		41	
34	47		44	
41	37		39	
41	40		35	
37	36		39	
37	31		28	
35	40		40	
34	44		40	
36.5		38.8	36.3	

OBSERVATIONS ACCORDING TO WEATHER AND BAROMETRIC CONDITIONS.

Cloudy Days. Barometer.			Fair Days. Barometer.		Clear Days. Barometer.				
Low.		High.	Low.		Low.			High.	
28.80 to 28.90	28.90 to 29.00	29.00	28.80 to 28.90	28.90 to 29.00	28.80 to 28.90	28.90 to 29.00	29.00 to 29.10	29.10 to 29.20	29.20 to 29.40
39	46	30	35	36	34	45	35	48	41
40	44	37	36	37	34	48	36	45	42
36	38	30	32	35	36	37	35	38	39
40	38	31	33	34	33	33	34	42	36
32	40	41	32	37		35	39	49	37
31	42	33	31	39		28	37	49	40
	39	36	45	33			30	35	52
	34	41	41	30			34	35	44
	31	38	36				36	22	42
	33	38	33				36	39	40
	37	31					40	35	33
	36	34					45	35	37
	35						38	55	44
	24						36	48	48
	34							36	36
	34							31	34
	35							34	39
	34							34	42
	41								
	41								
	37								
	33								
	37								
	37								
36.33	36.25	35.0	35.4	35.1	36.3		36.5	39.4	39.5

OBSERVATIONS ACCORDING TO VELOCITY OF THE WIND.

Miles,	0 – 3.	4 – 6.		7 – 9.	10 – 12.	13 – 15.	16 – 19.
	48	35	37	32	36	46	30
	45	35	38	33	37	44	37
	22	45	37	35	32	32	41
	32	48	40	34	31	31	41
	40	39	36	30	34	32	38
	42	40	31	34	34	31	38
	39	38	40	36	40	44	
	34	42	44	36	34	41	
	31	49	32	43	34	43	
	33	49	37	48	34	45	
	55	36	41	44	35	34	
	47	35	44	44	33	36	
	52	35	39	39	35	43	
	44	36	35	38	24	43	
	40	41	42	39	33	37	
	40	42	40	31	30	39	
	41	39	34	36	33	34	
	33	39	34	33	36	34	
	37	30	36	35	36		
	34	30	33	34	40		
	31	35	38	36	36		
	34	34	36	28	42		
	39	30	37		40		
	42	31	33		40		
		39	37				
		38	33				
Mean,	36		37.6	36.3	34.9	38.3	37.5

OBSERVATIONS ACCORDING TO DIRECTION OF WIND.

North.	North E.	East.	South E.	South.		South W.	West.	North W.
46	38	31	36	22	39	48	34	36
44	38	33	42	32	42	45	34	37
38	35	37	38	34	35	40	41	32
42	35	40	38	34	34	42	42	33
49	36	52		32		32	30	45
49	35	44		31		31	34	48
35	30	40		43		44	36	39
36	37	33		45		41	28	40
36	30	38		40		35		39
36	31	36		34		34		37
41	36			37		36		36
44	34			36		34		36
40	31			34		37		35
	34			36		39		33
				44		48		55
				43		48		47
				35		34		40
				35		34		44
				39		36		32
				39		41		37
				30		34		33
				30		34		30
				34		37		39
				34		33		35
				36		39		39
				31		31		38
				35		38		40
				24		37		40
				42		36		
				38		33		
				33				
				37				
				44				
				44				
				36				
				33				
				41				
				41				
41.2	34.3	38.4	38.5	36.1		37.7	34.9	38.4

OBSERVATIONS ACCORDING TO BAROMETRIC CONDITIONS AND THE VELOCITY OF THE WIND.

Barometer Below 29 Inches.		Barometer Above 29 Inches.		
Wind 8 Miles or Below.	Wind 8 Miles or Above.	Wind 8 Miles or Below.		Wind 8 Miles or Above.
38	46	48	36	43
38	44	45	36	45
35	36	38	37	40
35	37	42	40	34
32	32	49	36	34
33	32	49	31	36
45	31	36	40	44
48	31	35	44	43
39	45	33	37	35
40	41	35	44	35
40	34	36	39	34
42	34	41	35	34
39	37	42	32	30
34	36	39	44	37
31	34	39	40	35
33	24	39	40	33
35	37	30	40	33
34	39	30	42	37
44	33	36	40	34
44	30	34	43	34
34	34	41	47	39
34	36	30	40	38
36	36	31	33	36
33	32	39	36	42
37	40	38	33	38
33	41	30	31	38
37	41	34	34	40
37	35	36	38	40
36		36	36	39
28		55	39	31
		47	42	
Mean- 36.9	36		38.4	37

Mean Low Wind,- 36.9 + 38.4 = $\frac{75.3}{2}$ = 37.7

Mean High Wind,- 36 + 37 = $\frac{73}{2}$ = 36.5

OBSERVATIONS ACCORDING TO MOISTURE IN ATMOSPHERE.

.2 - .4 Inches.	.4 - .6 Inches.		.6 - .8 Inches.		.8 - .10. Inches.
46"	38"	39"	38"	33"	34
44	38	38	42	30	34
36	35	36	35	39	35
37	36	34	36	35	34
32	45	36	40	40	40
33	48	42	42	40	34
37	39	40	39	43	34
40	40	40	34	47	36
39	48	39	32	44	35
42	46	31	31	44	35
	49	37	32	34	30
	49	37	31	34	30
	36	35	44	36	33
	35	34	41	33	37
	22	36	31	38	34
	32	28	33	38	34
	36		43	31	36
	36		45	34	40
	35		37	38	
	33		36	33	
	55		41	36	
	47		42	41	
	36		44	41	
	36		43	37	
	36		38	33	
	32		39	36	
	35		34		
	24		34		
	40		30		
	44		38		
	37		36		
	39		34		
	41		30		
	44		31		
	52		39		
	44		37		
	42		30		
	40		34		
	40		32		
	33		37		
Means, 38.6	38.5		36.9		34.7

MEAN READINGS ACCORDING TO

(1) DIRECTION OF THE WIND:-

North, 41".2; North East, 38".4; East, 38".4;
South, 36".1; South East, 38".5; West, 34".9;
South West, 37".7; North West, 38".4.

(2) TEMPERATURE:-

63°-67°; 68°-72°; 73°-77°;
38" 35.3" 38"
78°-82°; 83°-87°; 88°-92°.
36" 37" 38".

(3) CLEAR DAYS, HIGH THERMOMETER,- 39".
LOW THERMOMETER,- 38".3.
FAIR DAYS, HIGH THERMOMETER,- 37".
LOW THERMOMETER,- 35".3.
CLOUDY DAYS, HIGH THERMOMETER,-35".4.
LOW THERMOMETER,- 36".6.

(4) VELOCITY OF THE WIND:-

Miles	Reading
0 - 3,	36".
4 - 6,	37".6.
7 - 9,	36".3.
10 -12,	34".9.
13 -15,	38".3.
16 -19,	37".5.

MEAN READINGS ACCORDING TO

(5) BAROMETER:-

28.79 to 28.89;	28.90 to 28.99;	29.00 to 29.07;
34".9	37".2.	36".5.
29.10 to 29.19;	29.20 to 29.29;	29.30 to 29.42;
36".3.	39".2.	39".6

(6) BAROMETRIC CONDITIONS AND WEATHER:-

Cloudy Days, Barometer	28.80 to 28.90	28.90 to 29.00	29.00 +	
	36.33	36.25	35	
Fair Days, Barometer	28.80 to 28.90	28.90 to 29.00		
	35.4	35.1		
Clear Days, Barometer.	28.80 to 28.90	29.00 to 29.10	29.10 to 29.20	29.20 to 29.40.
	36.3	36.5	39.4	39.5

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